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FA Report R-1773 Part II

PAD PROPELLANTS FOR USE AT HIGH TEMPERATURES
PART II - Exposure of Nitrate Ester Propellants to High Temperatures, and Ballistic Feasibility of Composite Propellants in PAD Cartridges

by

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TECHNICAL REPORT AFFDL-TR-65-29, Part II

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AIR FORCE FLIGHT DYNAMICS LABORATORY
Research and Technology Division
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FOREWORD

The research work described in this report was performed by the Frankford Arsenal, U.S. Army Munitions Command, Philadelphia, Penna., for the Air Force Flight Dynamics Laboratory (AFFDL). The task was accomplished under Project 1362, "Crew Escape for Flight Vehicles," and task 136205, "Propellant Actuated Devices Research." The program was funded by HIPRs numbers 33(616)60-17, 33(616)61-12, and 33(657)-2-R&D-111. Captain D. S. Barron was the AFFDL(FDFR) Project Engineer; Mr. Martin Visnov was the Frankford Arsenal Project Engineer. The work was performed during the period December 1959 to October 1962. This is Part II of three parts.

This report was submitted by the author 7 April 1965.

This technical report has been reviewed and is approved.

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ABSTRACT

Single and double base propellants as used in propellant actuated device (PAD) cartridges were subjected to high temperature conditions short of autoignition. Their thermal deterioration was measured by decay in peak pressures in firings in the M73 cartridge/M3 initiator system and by estimation of weight loss, change in nitrogen content of nitrocellulose, gas evolution, and grain deformation. The propellants degraded rapidly at 225° and 250° F and would not survive 275° F exposure to permit evaluation.

The ballistic feasibility of substituting composite propellants for nitrate esters in PAD cartridges was demonstrated in the M73 cartridge. This required hand-tailoring of grains, because composite propellants in gun-type geometries were not available from major composite propellant sources.

Composite propellants employing ammonium perchlorate oxidizer performed satisfactorily in the M73 cartridge/M3 initiator system at -65° F, but were marginal after two hours' exposure at 400° F.

It is recommended that efforts be continued for the development of composite propellants employing potassium perchlorate oxidizer to withstand -65° to +400° F soak temperatures.

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INTRODUCTION

This is the second report on the progress of the program for development of propellants for propellant actuated devices (PAD) to withstand temperatures up to 400° F. A previous report[1*] contained a literature survey and described the screening of a wide variety of nitrate ester and composite propellants by means of autoignition tests. Composite propellants, as a class, showed higher autoignition temperatures than single or double base propellants.

Although the autoignition tests furnished a reasonable idea of the absolute limit of propellant life under various time-temperature conditions, they did not measure the extent of propellant deterioration under heat conditions short of autoignition, which results in substandard functioning. This information did not exist for the nitrate ester propellants used in PAD.

A second area to be explored was the composite propellant, now shown to be more resistant to heat than the nitrate esters. While composite propellants were common in rockets and gas generators, their application to small cartridge actuated devices was virtually unknown. The ballistic feasibility of substituting composites for gun-type single and double base propellants in PAD had yet to be shown.

TECHNICAL APPROACH

Study of the effect of high temperature exposures on the nitrate ester propellants in PAD was conducted by both laboratory examination of degraded propellant and ballistic firings of M73 PAD cartridges in the M3 initiator ballistic test system. Laboratory studies included estimation of weight loss, change in nitrogen content of nitrocellulose, gas evolution, and physical examination of heated grains for change in geometry and other effects. Propellant decomposition gases were analyzed by mass spectrometer.

In addition to ballistic studies of heated nitrate ester propellants, the M73 PAD cartridge/M3 initiator system was chosen as the vehicle for attempts to substitute composite propellants for nitrate esters. The reasons for this were several: First - it was the most widely used PAD cartridge and was representative of a class of small propellant actuated devices. Second - the M73 cartridge uses less than three grams of propellant. This made available a simple PAD ballistic system small enough to conduct numerous test firings of new propellant compositions that were obtainable only in experimental

*See REFERENCES.

quantities. Third - the small size of the M73 cartridge provided a minimum hazard in heating experimental formulations. Fourth - the same cartridge was adapted for the other thermal stability work and thus enabled closer correlation between the stability and performance tests.

EXPERIMENTAL PROCEDURE

Effects of Severe Heat on Nitrate Ester Propellants

In this study, at least two sets of M73 cartridges were heated simultaneously under gradually more severe time-temperature conditions. One set of cartridges contained propellant only, and was set aside for degradation studies in the laboratory. The second set of cartridges consisted of the propellant charge (approximately 2.8 grams) and one gram of the standard A4 black powder igniter. With the exception of certain series of cartridges where data on the effects of heat on the percussion primer were desired, the cartridges were primed after heat exposure. The primed cartridges were then fired in the M3 initiator, using the specification test fixture of 15 feet of M28741-4 high pressure aircraft hose terminating in a one cubic inch volume chamber.

The heated cartridges containing propellant only were first ruptured in a sealed system, and gas content was analyzed by mass spectrometer. The propellant grains were examined for significant grain deformation or other change, and weight loss was determined. Samples of the propellant were then subjected to further analysis, as desired.

In the previous report,[1] it was shown that the nitrate ester propellants in sealed PAD cartridges would autoignite in a matter of minutes at constant temperatures above 300° F. As expected, induction periods were longer at lower constant temperatures, until tests were terminated at 12 hours at the 225° F level. Consequently, for this phase, work was conducted beginning with exposures of the nitrate ester propellants at 225° F and raised by 25° intervals.

Two double base propellants and one single base propellant were chosen as typical nitrate esters for evaluation. These propellants were standard charges for the M73 cartridge at various times. They were: Lot RAD 7944 - M5, double base (approximately 15 percent nitroglycerin); Lot RAD 5280 - M2, double base (approximately 20 percent nitroglycerin); and Lot PAE 4228 - M10, single base.

Feasibility of Composite Propellants in PAD Cartridges

The experiments for this phase consisted of firing composite propellants, which had shown heat resistance superior to nitrate esters, in the M73 cartridge/M3 initiator system in an effort to match the ballistics of the nitrate ester. The main problem was one of sizing the composites into very small grains. As indicated before, composite propellants were oriented toward relatively large grains for rocket motors and gas generators. Most of them were castable compositions which are poured as a slurry into the motor casing and cured in-place to a rubbery solid. A few were extrudable, but were obtainable only as very small diameter solid rods.

Of the composites evaluated here for ballistic feasibility in PAD, samples of AN 583AF, ANT 623, and Arcite 377 propellants* were received as large, irregular blocks, weighing up to several pounds each and apparently cut from motor grains. These required cutting and machining to cylindrical rods of 0.2 inch diameter. Several extrudable compositions were obtained as a result of an extensive survey of composite propellant sources. ANR 2753BI was obtained in 3/8 inch diameter rods. GCR 400, GCR 310, GCR 700, and GCR 701 propellants* were obtained in solid rod extrusions of 0.1, 0.2, and 0.5 inch diameters. One propellant, Arcite 406,* was actually cast into small rods of 0.1, 0.2, and 0.5 inch diameters. These small diameter, cast rods were later found to be porous.

Several geometries of small grain composite propellants were fired. For perforated grains, longitudinal holes were simply drilled in the machined cylindrical rods (Figure 1). In later firings, the rods were sliced into discs.

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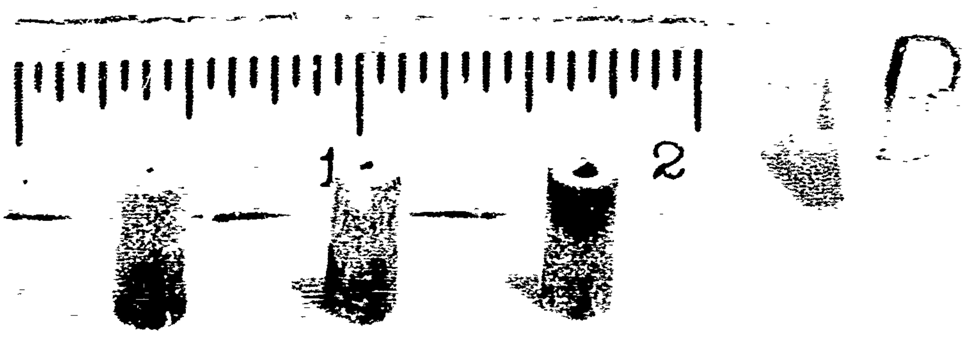

Figure 1. Machined Small Grain Composite Propellant

*For compositions of these propellants, see Reference 1.

A propellant slicer (Figure 2) was devised in order to cut discs of reproducible thickness. In operation, the rod of propellant was inserted into the hollow bolt and forced against the backstop by a spring-loaded piston. Cuts were made by an ordinary razor blade held in a fixed plane by a bracket. Discs of various reproducible thicknesses could be cut by adjusting the position of the bracket.

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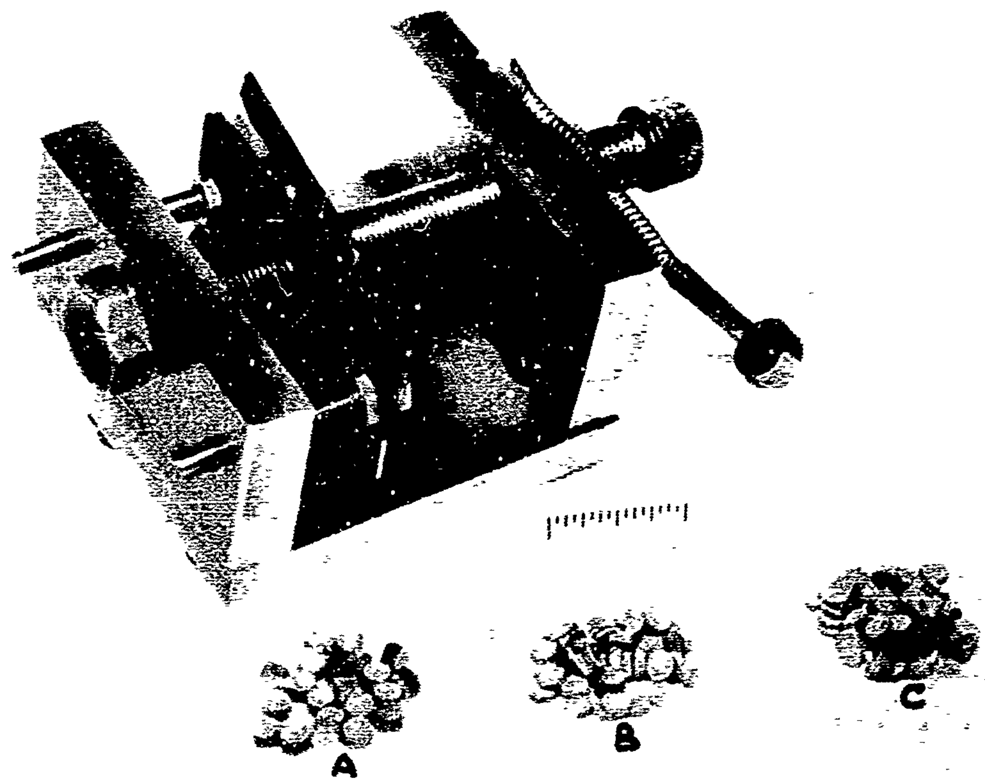

Figure 2. Hand Slicer and Disc Composite Grains

RESULTS

Exposure of Nitrate Ester Propellants to High Temperature

Ballistic Performances in M73 Cartridges

M5 Double Base Propellant

Unprimed M73 cartridges, loaded with M5 propellant (Lot RAD 7944) and A4 black powder igniter, were conditioned at 225°, 250°, and 275° F for gradually increasing time periods at each temperature. The cartridges were removed at each time interval, primed with 72M styphnate primers, and fired in the M3 initiator ballistic test system. Comparison was made with unheated control cartridges. Individual round data are shown in Appendix I.

In the exposures at 225° F, the first evidence of a lowering in peak pressure appeared at 48 hours. Peak pressures continued to drop as exposure time increased beyond 48 hours. When the cartridges were removed from the oven, it was noted that some of the 48-hour exposed cartridges were slightly swelled at the shoulder and base. The swelling of some cartridges was more pronounced in the 72-hour and longer exposures (Figure 3). In some instances, case distortion was severe enough to require pressing the cartridges by machine into the cartridge retainer basket in order to permit assembly of the initiators for firing. The swelling of the cases was attributed to internal pressure exerted by propellant decomposition gases under heat.

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Unexposed — 72 Hours at 225° F

Figure 3. M73 Cartridges (with M5 Propellant), showing Swelling after 72 hours' Exposure at 225° F

In the exposures at 250° F, one cartridge showed a low peak pressure at eight hours, and a general lowering of peak pressures was noted beginning with ten hours. The reason for the uptrend in pressures at 14 hours is not known, although erratic behavior in exposures at 250° F for 14 hours and longer was noted during the experiments. Previous autoignition data had suggested that exposures of M5 propellant in sealed PAD cartridges for periods longer than 12 hours at 250° F would be marginal. Consequently, the number of cartridges was doubled to ten in order to define this area more closely.

It is seen from the firing data for 14 hours that one peak pressure was low. Although not shown in Appendix I, similar erratic peak pressures were obtained for the 250° F/16 hour exposure. When attempts were made to rerun the 250° F/16 hour exposure, four cartridges autoignited in the oven. In each attempt to lengthen the exposure to 18 and 20 hours at 250° F, several cartridges ignited during the heating period.

All attempts at 275° F exposure for one- or two-hour periods resulted in a number of exploded cartridges. This agrees with previously reported autoignition data for M5 propellant at this temperature.

No further attempts were made to increase the severity of exposure for the M5 propellant/M73 cartridge.

M2 Double Base Propellant

A large number of M73 cartridges were loaded with M2 propellant (Lot RAD 5280), black powder igniter, and 72M styphnate primers, and conditioned at 225° and 250° F. Withdrawals of 225° F conditioned cartridges were made at 24-hour intervals. Between the 72-hour and 96-hour withdrawals, 17 cartridges ignited in the oven. The withdrawn cartridges were also swelled. All cartridges which had survived heat exposure were fired in the M73 initiator ballistic test system. A number of primer misfires were encountered. Individual round firing data are shown in Appendix II. The first lowering of peak pressures is noticeable beginning with 72 hours.

Due to the number of exploded cartridges, there were not enough remaining to continue beyond 120 hours. The 225° F exposures were repeated, using more cartridges. During the second run, cartridge autoignitions occurred at the same intervals (72 to 120 hours) as in the first run. Exposure was terminated at 144 hours. Individual round data for the cartridges surviving the repeat run are also shown in Appendix II. Misfires were encountered again. The drop in peak pressure level with increased exposure time paralleled the first series. The trend continued at 144 hours.

Withdrawals of cartridges conditioned at 250° F were made at two-hour intervals. The test could not be carried out beyond eight hours due to cartridge explosions between the eight- and ten-hour intervals. Firing data for the exposed cartridges are shown in Appendix II. Peak pressures remained at the same level for all exposures.

No attempt was made at 275° F exposures of the M2 propellant/M73 cartridge because previous autoignition data, verified by M5 propellant experience, indicated less than one-hour survival.

M10 Single Base Propellant

Ballistic evaluation was conducted of 225° F exposed M10 single base propellant (Lot PAE 4228) in M73 cartridges. The cartridges were loaded with propellant and black powder igniter, and primed with the 72M styphnate primer. Exposures continued up to 216 hours.

At the 120-hour withdrawal, a slight swelling was noted at the base of a number of cartridges. Beginning with 144 hours, virtually all the cartridges showed increased swelling. Firing data are shown in Appendix III.

The peak pressure level for this charge is slightly lower than that of M5 or M2 double base charges for this same cartridge. In Appendix III, the first peak pressure drop of M10 single base propellant appears at 96 hours. As peak pressured dropped, there was a simultaneous increase in rise time (defined as the time interval, in milliseconds, from initial rise in pressure to maximum pressure) as recorded on the oscillograph trace.

Although the data for M10 single base propellant at high temperature show slightly increased life over that for the double base propellants, it was not considered sufficient to warrant further firings of M10 propellant exposed to 250° F or higher.

Laboratory Study of Propellants

Propellant Weight Loss in Sealed Cartridges

Sealed cartridges of nitrate ester propellants were heated simultaneously with those for the ballistic evaluation described above. Cooled cartridges were first tapped for gas content; then opened and propellant weight loss determined. Weight loss data at 225° F are shown in Appendix IV and Figure 4, beginning with the 24-hour exposures and encompassing the time period of lowering in ballistic properties.

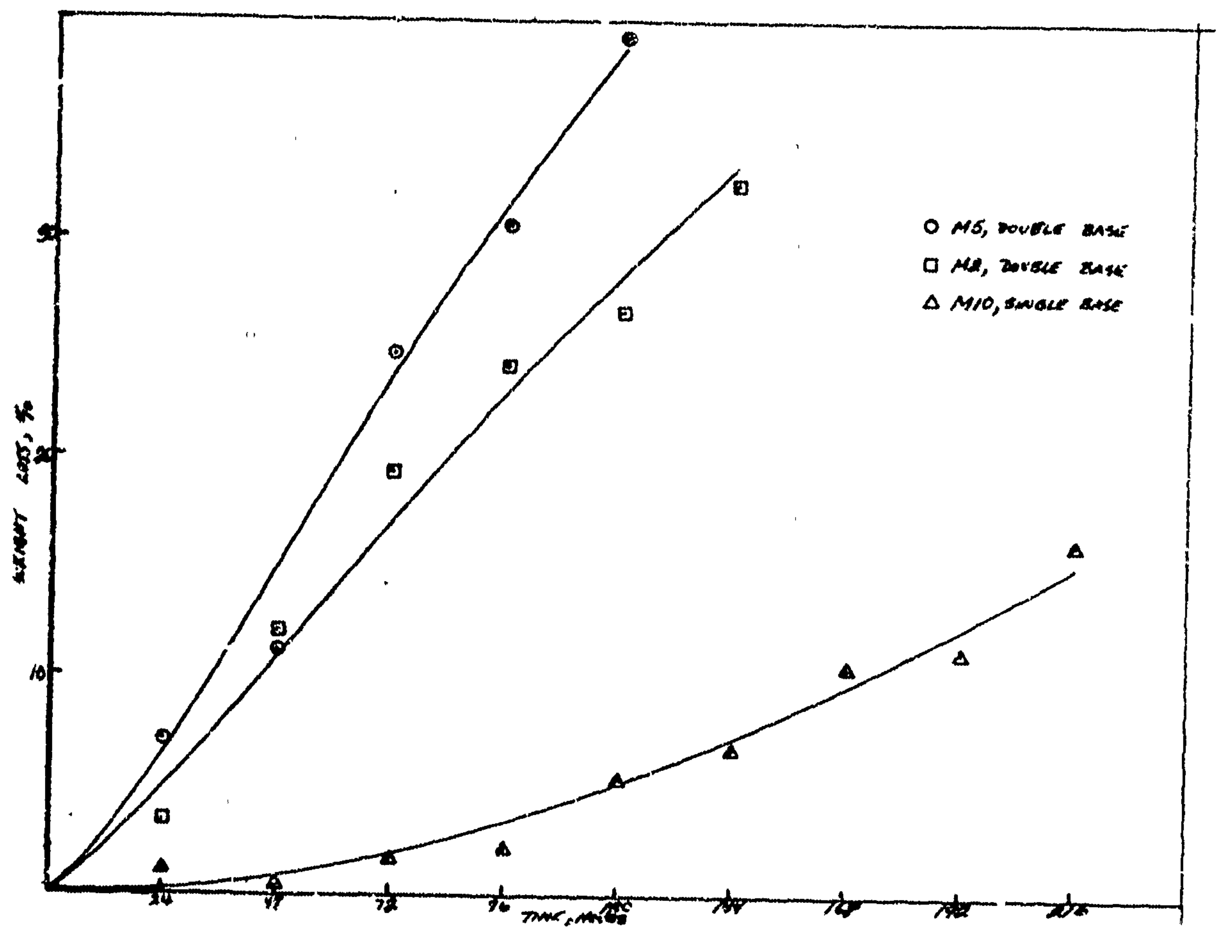

Figure 4. Weight Loss vs Time at 225° F, Nitrate Ester Propellants

Lower rate of weight loss for M10 single base propellant, compared to the double base, is obvious. At the longer exposures, the gross effects of heat were clearly evident, even on visual examination (Figure 5). Also noted in a number of the longer exposures was a brown, sticky residue which coated the interior of the cartridge cases.

Due to the rapid rate of deterioration at 250° and 275° F, as shown by previous autoignition data and cartridge explosions in the oven, weight loss at these temperatures was not determined.

Nitrogen Content of Nitrocellulose

As a measure of the loss in energy of the nitrate ester propellants, attempts were made to determine the nitrogen content of propellant nitrocelluiose in 225° F heated double base propellant (M5) and single base propellant (M10). The method employed was analysis by duPont Nitrometer. Typical data obtained are shown in Appendix V.

Although a gradual drop in nitrogen content with increased exposure time is indicated, the validity of the quantitative results is questionable when the amounts of recoverable nitrocellulose for M5 propellant (shown in Appendix V) are taken into account. The explanation follows.

The procedure for determining nitrogen in propellant nitrocellulose requires the separation of the other propellant ingredients from the nitrocellulose by extraction with methylene chloride. When the propellant is degraded by heat, the nitrocellulose loses nitrogen - via split off of NO_2 groups - in random fashion. When the heated M5 propellant was analyzed, it was found that the more severely degraded nitrocellulose and its products remained dissolved in the extraction solvent, leaving the disproportionately high nitrogen fraction for determination of nitrogen.

A revised extraction procedure resulted in improved recovery and a more representative sample of nitrocellulose from the heated propellant. However, as is seen in Appendix V, even with an improved procedure, the amount of recoverable nitrocellulose decreased as length of heat exposure increased. Part of this drop in recoverable nitrocellulose may also be attributed to the disappearance of the cellulosic structure itself via cleavage into aldehydes, CO_2, H_2O, and other decomposition products.

Gas Content of Heated Cartridges

Prior to examination of the propellant, the sealed M73 cartridges which had been heated were tapped for gas content analysis.

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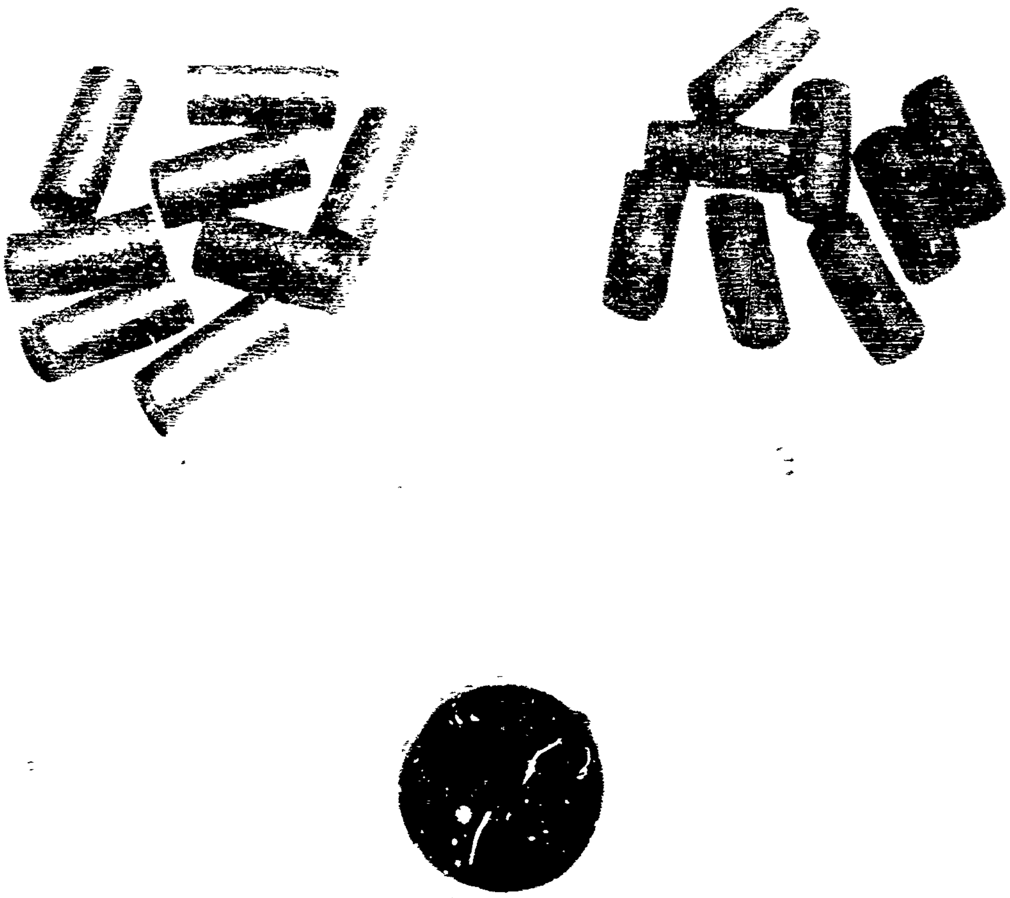

C

Figure 5. Thermally Degraded M2 Propellant from Sealed PAD Cartridges

A - Unexposed
B - 120 hours at 225° F
C - 144 hours at 225° F

The cartridges were placed in a closed system which included a gas sampling bulb. The system was evacuated to 20 microns (Hg) and the cartridge was ruptured by means of a sharp pin. The cartridge atmospheres were analyzed on a Consolidated Electrodynamics model 21-103 mass spectrometer.

Note should be made of how the mass spectrometer data were handled. Ordinarily, quantitative mass spectrometer analyses of gas mixtures are based on partial pressures of the individual gases. The mole percent estimate is usually obtained by "normalizing" the total of partial pressures to 100 percent. However, in this program, the mole percent for each component gas was obtained by dividing each partial pressure by the pressure of the total decomposition gas mixture as actually measured by the micromanometer of the mass spectrometer inlet system. This method may not total exactly 100 percent, but it will indicate whether all gases present have been identified.

Analyses of cartridge atmospheres from the heated nitrate ester propellants are shown in Appendices VI, VII, and VIII. Since the cartridges were loaded under ambient conditions, mass spectrometer analysis of a typical dry air sample is shown for comparison. Also shown is the atmosphere analysis of duplicate unheated control cartridges with M5 propellant (Appendix VI).

The absence of oxides of nitrogen or sizable quantities of oxides of carbon show the original condition of the propellant to be satisfactory. (All nitrate ester propellants passed the methyl violet heat stability test prior to high temperature exposures.) It is seen that the atmosphere inside the unheated cartridges was essentially air plus small amounts of volatiles from the propellant.

The degradation of the propellants due to heat is evident from Appendices VI through VIII. Apparently, the oxygen inside the sealed cartridge is consumed very early in the decomposition process, as evidenced by its virtual disappearance before 24 hours at 225° F or two hours at 250° F. The oxygen loss is accompanied by an immediate rise in carbon oxides and the appearance of nitrous and nitric oxides, indicating breakdown of the propellant. Not shown in the Tables were peaks in the spectra, indicating -CHO grouping, verifying results of investigators who have reported aldehydes as one of the products of thermal decomposition of nitrocellulose.

The amounts of gas shown in the Tables (calculated from sample bulb pressures measured at the inlet system of the mass spectrometer) are inconsistent with heating time. It is believed that this is due partly to losses through cartridge O-ring seals deteriorated by heat. Even with the randomness of measured gas volumes, it is seen that the M10 single base propellant evolved gas at a slower rate than did the double base propellants at 225° F.

Single Perforated Cylindrical Grain Geometry

The first test firings of composite propellants were conducted in the M38 cartridge (an earlier version of the M73 cartridge with identical propellant capacity). AN 583AF and Arcite 377 composites were fired. The properties of both propellants, although not exact duplications of the M5 double base charge, were sufficient to warrant testing.

Both propellants had a calculated value of approximately 0.04 mole of gas per gram, and a calculated impetus in excess of 300,000 ft-lb per lb. Linear burning rates at 5000 psi - the chamber pressure of the M3 initiator in which the cartridges were fired - were not known, although estimated to be slower than the M5 double base. Small cylindrical grains, 0.20 inch in diameter, were machined from bulk samples of the propellants. Three different size perforations were bored in the grains, resulting in three web thicknesses, the thinnest of which (0.053 inch) did not match the 0.039 inch web of the seven-perforated M5 grain. Thinner webs could not be made without crumbling the wall of the grain. The M38 cartridges were loaded with eight grains of the propellant and one gram of A4 black powder, and primed with 72M styphnate primers.

The cartridges were fired in M3 initiators, at ambient temperatures, using the specification test fixture of 15 feet of hose and a one cubic inch test chamber. A standard M38 cartridge, loaded with M5 propellant, was fired for comparison. The following (Table 1) are the data obtained.

TABLE 1
Ballistic Data, Cylindrical Single Perforated Propellant Grains
in M38 Cartridge

Propellant	Charge (gm)	Web (in.)	Peak Pressure (psi)	Time (ms) Ignition Delay	Time (ms) Rise
M5 (standard)	2.80	0.039	1200	13	27
Arcite 377	2.40	0.053	a	a	a
	2.73	0.068	592	13	97
	2.92	0.083	586	20	130
AN 583AF	2.40	0.053	608	15	75
	2.71	0.068	533	15	120
	2.95	0.083	600	15	145

[a]Faulty data; range manfunction.

Peak pressures of the composite propellants were lower than the double base standard. The other data indicated normal propellant behavior in that ignition was satisfactory and time to peak pressure was dependent on web thickness. Also, even if it could be made, a burning web in the single perforated geometry of the composites comparable in thinness to the seven-perforated M5 propellant would limit the propellant weight. A propellant geometry that provided increased surface area was required. Lastly, to attain peak pressures within shorter rise times, composite propellants with faster burning rates were necessary.

Disc Grain Geometry

In view of the results of firings of composite propellants in the single perforated cylindrical geometry, an effort was made to increase peak pressure by increasing initial burning surface area. Since machining thinner web cylinders was impractical, it was decided to employ discs sliced from solid rods of propellant.

In this geometry, disc thickness became the web. Discs 0.125 in., 0.060 in. and 0.040 in. thick are shown in Figure 2 (A, B, and C, respectively). These webs were employed in the initial test firings of AN 583AF composite propellants in this geometry. The propellants were fired in the same system as the cylindrical grains. M5 double base was fired for comparison. Data are shown in Table 2.

TABLE 2.
Ballistic Data, M38 Cartridge with Propellant of Varied Disc Thickness

Propellant	Charge (gm)	Web (in.)	Peak Pressure (psi)	Ignition Delay (ms)
M5 (standard)	2.80	0.039	930	17
	2.80	0.039	[illegible]	17
	2.80	0.039	1020	18
AN 583AF (disc)	2.40	0.040	620	16
	2.40	0.060	500	19
	2.34	0.125	290	30

Peak pressures of the composites were lower than those of the double base, but the dependence of peak pressure on burning web thickness of the discs was demonstrated. Lower peak pressures were again attributed to a combination of slow burning rate and reduced charge weight of the AN 583AF propellant.

The second series of firings of disc geometries was conducted with four composite propellants different from those previously fired. These were obtained in specified formulations of faster burning rate. Three of the propellants (GCR 400, GCR 700, and ANR 2753BI) were experimental formulations, extrudable in small diameter rods (Figure 6.) The fourth (ANI 623) was a castable composition which required machining to rod form. Discs of propellant 0.040 inch thick were cut from rods 0.1 and 0.2 inch diameter, and the firings in M38 cartridges were repeated. Again, M5 double base was fired for comparison. Data obtained are shown in Table 3.

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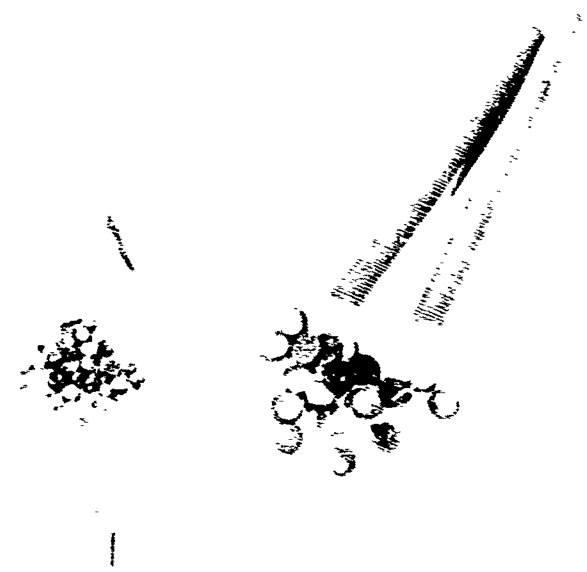


Figure 6. Solid Rod Extrusions, Composite Propellant

It can be seen that the performance of the double base propellant in the M38 cartridge/M3 initiator system was met by the composite propellants tested in the disc geometry configuration.

Another series of firings was held to determine the reproducibility of the previous performance. This series included both repeat firings of the previous disc composite propellants and firings with additional propellants. The latter included Arcite 406, a composite cast into small rods of 0.1 and 0.2 inch diameter; GCR 310 propellant, an extrudable composite containing lithium perchlorate oxidizer; and GCR 701, an extrudable composite containing an experimental burning rate

TABLE 3.
Ballistic Data, M38 Cartridge with Prope[illegible]nt of 0.040 inch Disc Thickness

Propellant	Charge Weight (gm)	Web (in.)	O.D. (in.)	Peak Pressure (psi)	Time (ms) Ignition Delay	Rise
M5 (standard)	2.8	0.039	-	880	17	21
	2.8	0.039	-	930	16	20
GCR 400[a]	2.5	0.040	0.20	1040	14	15
	2.5	0.040	0.20	1020	13	19
	2.5	0.040	0.10	960	15	17
	2.5	0.040	0.10	1010	15	20
GCR 700[a]	2.5	0.040	0.10	1015	13	16
	2.5	0.040	0.10	920	10	19
ANT 623[a]	2.5	0.040	0.10	930	13	19
	2.5	0.040	0.10	980	11	21
ANR 2753BI[a]	2.5	0.040	0.20	950	13	19
	2.5	0.040	0.20	980	13	19
	2.5	0.040	0.10	1030	13	19
	2.5	0.040	0.10	1050	13	16

[a]Disc.

additive. These three propellants w[illegible] sliced into 0.040 inch discs, similar to the others. Beginning with this series, firings were held in the M73 cartridge (replacement for the M38) in the identical M3 initiator ballistic test system. Results are shown in Appendix IX.

The original propellants (fired in the previous series) again equalled the standard M5 double base charge, but the peak pressures for Arcite 406 were erratic and for GCR 310, low. Due to the varied ballistics obtained with Arcite 406 and GCR 310, these propellants were refired in triplicate for each disc size. Data obtained are shown in Table 4.

Peak pressures were higher for Arcite 406, but were still low for GCR 310. In the midst of these firings, other examination in the laboratory detected undesirable characteristics in these two propellants. When exposed to ambient conditions, GCR 310 propellant was found to be somewhat hygroscopic, resulting in oxidizer crystal growth on the surface of the propellant. As a result of this, plus substandard ballistics, no further work was done with GCR 310. In the case of Arcite 406, a considerable number of grains were found to be porous. This porosity apparently had not been detected by the 100 percent X-ray inspection required of the small rod castings. Further firings of this propellant were done with hand-culled discs, but since there was a possibility of undetected porosity, the data were discarded. (The manufacturer of this propellant later developed an extrusion process for Arcite propellants, but none of these extruded Arcites were obtainable at the time of this work.)

TABLE 4.
Ballistic Data, Repeat Firings of
Arcite 406 and GCR 310 Propellant Discs in M38 Cartridge

Propellant	Charge Weight (gm)	Web (in.)	O.D. (in.)	Peak Pressure (psi)	Rise (ms) Ignition Delay	Rise
M5 (standard)	2.85	0.039	-	1050	14	23
	2.85	0.039	-	1250	23	25
Arcite 406[a]	2.5	0.040	0.10	880	15	20
	2.5	0.040	0.10	1000	14	18
	2.5	0.040	0.10	1050	16	14
	2.5	0.040	0.20	980	14	21
	2.5	0.040	0.20	1030	13	16
	2.5	0.040	0.20	1080	15	19
GCR 310[a]	2.5	0.040	0.10	620	23	19
	2.5	0.040	0.10	760	19	20
	2.5	0.040	0.10	850	16	20

[a]Disc

Graphite-coated Disc Geometry

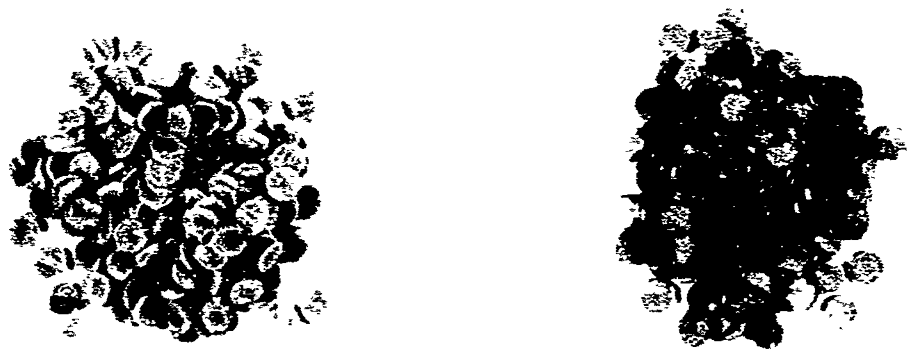
Small nitrate ester propellant grains in gun geometries are usually graphite-coated to promote free flow and prevent electrostatic charge build-up during loading operations. The increased lubricity allows greater packing density in cartridge cases. The small composite propellant disc grains were being evaluated without coating. The freshly cut discs showed some resistance to flow and difficulties were encountered in loading cases with the desired charge weight. Quantities of small composite grains in both 0.1 and 0.2 inch diameters were coated with graphite to approximately 0.5 percent by weight. Two samples are shown in Figure 7. Experimental loadings with these grains showed that up to ten percent increased packing could be attained in the M73 cartridge over that with uncoated grains.

Test firings were held to determine if ignition delay, rise time, and peak pressures would differ from previously fired uncoated composites. Charge of 2.5 and 2.7 grams of graphite-coated propellant and one gram of black powder were loaded in the M73

Neg 36.231.S3062/ORD.59

Base Grain **Graphited**

0.1 inch O.D. Composite Grains



Base Grain **Graphited**

0.2 inch O.D. Composite Grains

Figure 7. Graphite-coated Composite Propellant Disc Grains

cartridge case. The 2.7-gram charge weight was previously unattainable. Firings were done in the M3 initiator test system. Data are shown in Appendix X.

Ignition delay, rise time, and peak pressures were not adversely affected by the graphite coating. A general increase in peak pressure with the added 0.2 gram of propellant charge can be seen for each composite propellant. In the case of GCR 701, this resulted in a more acceptable peak pressure level, and the 2.7-gram charge for the M73 cartridge was used for all additional work with this propellant. For the remainder of the composite propellants, 2.5-gram charges were continued. All further firings employed graphite-coated grains.

Firing of Composite Propellants Exposed from -65° to +400° F

Since it had been demonstrated that composite propellants could match the ballistics obtained with nitrate ester propellants in the M73 cartridge, an evaluation was then undertaken of the composite propellants exposed to low and high temperatures. ANR 2753BI, GCR 400, GCR 700, and GCR 701 propellants were fired at -65° F in the M73 cartridge/M3 initiator system. Peak pressure, ignition delay, and rise times (Appendix XI) showed little or no difference from previous ambient temperature firings.

High temperature exposures of the composite propellants in the graphite-coated disc geometry were conducted at 400° F, in accordance with the objectives of the program.

M73 cartridges, loaded with Arcite 406 propellant, were exposed at 400° F for two- and four-hour durations, in lots of five. During each of the conditioning periods, at least one or two of the cartridges exploded in the oven. When the remaining cartridges were fired at ambient temperature, peak pressures varied from the 900 psi level for the 400° F/2 hr exposures to 400 to 500 psi for the 400° F/4 hr exposures. As a result of these data, together with the previously described grain porosity, no further work was done with Arcite 406 propellant.

M73 cartridges, loaded with GCR 400, GCR 700, and GCR 701 propellants and black powder igniter, were conditioned at 400° F for two- and four-hour periods and fired at ambient temperature. Unheated M5 double base charges were fired for comparison. Firing data are shown in Appendix XII. Although all firings were within close ballistic limits, several peak pressures had dropped to the 800 to 900 psi level, particularly among the 400° F/4 hr exposures.

When 400° F/4 hr exposures were repeated, one GCR 400 and one GCR 700 cartridge ignited in the oven between the third and fourth hour of heating. When exposures of GCR 400, GCR 700, and GCR 701 propellants were extended to six and eight hours at 400° F, no autoignition occurred. When the cartridges were fired, peak pressures were generally satisfactory, but a few rounds dropped to the 600 to 700 psi level.

DISCUSSION

Exposure of Nitrate Ester Propellants to High Temperature

In the previous report on this work, autoignition tests had shown clearly that propellants based on the $-O-NO_2$ linkage could not survive at 400° F without autoignition. The experiments in this report, both ballistic evaluation and laboratory examination, serve to point out the rapidity of deterioration of these propellants, even at temperatures of 225° and 250° F. It is significant that no data could be obtained on the nitrate ester propellants heated in sealed PAD cartridges at 275° F because of the rapidity of decomposition and autoignition during the heating periods of one or two hours.

The conclusion (originally based on autoignition time vs temperature data of the previous report) that single base propellant (M10) had slightly longer life at high temperature than double base propellant (M5 and M2) was verified by data obtained here. When compared in the same ballistic system, peak pressures of the heated single base propellant began to decrease after longer induction periods than similarly heated double base propellants. Also, laboratory measurements showed that the single base propellant lost weight and evolved gas at a slower rate than the double base propellants.

It should be noted that the quantitative results of the weight loss, nitrogen content of nitrocellulose, and gas evolution measurements, as conducted here, would be expected to differ from similarly conducted experiments where propellant was heated while exposed to the atmosphere.

The data collected here are of propellant as it would be actually sealed in a production PAD cartridge. By specification, the cartridge seal is required to withstand 14 psi pressure differential. The result is that the propellant is more or less "cooked under pressure" when heated, and cooled to ambient conditions when examined. The over-all effect is faster deterioration since, for nitrate ester propellants, it is well known that the decomposition rate will be accelerated if the products of decomposition remain in contact with the propellant under pressure. Individually, the weight loss data are affected in that products which are volatile at heating temperature are trapped within the limits of the seal and may condense when the cartridge is cooled. The nitrocellulose nitrogen and evolved gas data are affected in that they are dependent on the decomposition rate and subject to change as the pressure builds up within the cartridge with heating time.

Ballistic Feasibility of Composite Propellants in PAD Cartridges

Firings of the composite propellants in the M73 cartridge/M3 initiator system demonstrated that, with the proper geometry, the ballistics obtained with the nitrate esters could be matched. However, in the process of achieving this result, several gaps in propellant technology were made evident. Primarily, in the search for composite propellants for this application, it was found that the technology did not exist among the major sources of composites for extrusion into very small monoperforated or multiperforated gun type grains. Contact with the major composite propellant producers established that requirements for composite propellants in such small geometries simply did not exist and, as far as was known, this was the first request.

Although the ballistics of a PAD device using a standard double base propellant grain were met here by the disc geometry, this solution is far from optimum for the wide range of PAD devices. The disc geometry is too limited for other pressure-time curves which require a greater degree of progressivity or, for that matter, any application which requires small grains in other than solid cylindrical form.

Another gap which appeared was the lack of information on burning characteristics of composite propellants in the higher pressure ranges at which most PAD devices operate. Because of their application, laminar burning rate data for nitrate ester gun propellants are available up to the high pressures developed in gun chambers. By comparison, similar data for composite propellants are usually developed only up to 2000 psi, a pressure above which rocket motors are rarely designed to operate. Straight line extrapolation of composite propellant burning rata data to higher pressures is open to question. For the M73 cartridge/M3 initiator system, which operates at approximately 5000 psi in the initiator chamber, this lack of data necessitated a trial-and-error approach.

Firings of the composite propellants at -65° F resulted in peak pressures of the same level as obtained with firings at ambient temperature (70° F). One phenomenon looked for was possible embrittlement of propellant binders at low temperature, resulting in grain fracture at ignition and unusually high pressures as a result of the increased surface area. There was no evidence that this occurred.

Experience with the cartridges of composite propellants exposed to 400° F indicates that the condition of these particular formulations is marginal after two hours at 400° F. Evidence of this is in the premature ignitions in the oven between three and fours hours at 400° F and the slight lowering in peak pressures of those cartridges which survived four hours at 400° F. The ignitions in the oven are at variance with autoignition data previously reported for these propellants.[1] However, the marginal thermal stability of ammonium perchlorate in the range of 400° F has been reported in Reference 1 and other investigations.[2,3] The greater thermal stability of potassium perchlorate over ammonium perchlorate in similar propellant binders was also shown.

In summary, the development of extrudable composite propellants employing potassium perchlorate oxidizer was indicated to meet the high temperature objective of the program.

CONCLUSIONS

1. The extent of nitrate ester propellant deterioration under high temperature conditions short of autoignition was measured by both ballistic firings in a standard propellant actuated device system and by examination in the laboratory. These propellants degraded rapidly at temperatures of 225° F and 250° F. The nitrate ester propellants (single or double base) are not suitable for PAD cartridges for 400° F resistance.

2. The ballistic feasibility of substituting composite propellants for nitrate esters was demonstrated in a standard propellant actuated device system, the M73 cartridge/M3 initiator. This required hand-tailoring of propellant grains limited to a simple disc geometry. The technology for extruding small gun type composite propellant grains did not exist among the major sources of composite propellants because of no previous requirement for such an item.

3. The disc geometry composite propellants employing ammonium perchlorate oxidizer performed well at -65° F, but were marginal after two hours' exposure at 400° F.

RECOMMENDATIONS

As a result of these studies, it is recommended that efforts be continued for the development of composite propellant compositions capable of reliable performance after withstanding -65° to +400° F soak temperatures. These compositions should employ potassium perchlorate oxidizers.[1] Also, these compositions should be capable of processing by commercially feasible methods (i.e., extrusion) into small gun type grains, including both monoperforated and multiperforated geometries.

[redacted]

APPENDIX I

BALLISTIC DATA, HIGH TEMPERATURE-EXPOSED M5 PROPELLANT
IN M73 CARTRIDGE/M3 INITIATOR SYSTEM

Firing temperature: 70° F (ambient)

Exposure	Peak Pressure (psi)	Time (ms) Ignition Delay	Rise
Unheated control	1060	16	21
225° F/4 hr	1060	18	20
	960	14	20
	1070	16	23
	1070	16	23
	1000	15	23
225° F/6 hr	1070	16	23
	1030	18	23
	970	18	23
	970	18	25
	1110	16	21
Unheated control	1020	11	29
225° F/12 hr	1080	20	29
	1050	13	30
	1060	13	17
	990	13	30
	950	13	29
Unheated control	980	13	30
225° F/16 hr	990	11	29
	870	11	31
	950	15	25
	960	14	24
	950	11	29
Unheated control	870	15	28
225° F/24 hr	1070	13	25
	950	10	30
	930	15	25
	910	13	26
	960	9	28

Exposure	Peak Pressure (psi)	Time (ms) Ignition Delay	Rise
Unheated control	940	13	26
225° F/48 hr	850	14	24
	880	14	21
	850	14	23
	860	14	24
	820	14	28
Unheated control	1020	13	24
225° F/72 hr	540	20	25
	640	16	24
	680	20	28
	610	13	20
	680	10	24
Unheated control	890	16	25
225° F/96 hr	650	20	20
	680	15	24
	420	20	25
	570	18	25
	[a]		
Unheated control	900	18	24
225° F/120 hr	190	38	40
	670	15	20
	680	13	20
	420	25	25
	430	26	29
Unheated control	970	18	15
225° F/144 hr	260	25	20
	630	14	19
	590	18	19
	510	15	20
	530	18	18
Unheated control	980	20	20

[a]No record; range malfunction.

Exposure	Peak Pressure (psi)	Time (ms) Ignition Delay	Rise
	250° F Exposures		
Unheated control	980	15	23
250° F/4 hr	900	16	20
	1030	14	21
	1110	14	19
	1070	16	21
	940	18	21
Unheated control	1170	18	20
250° F/6 hr	1180	14	21
	1270	16	20
	1140	18	21
	1010	18	23
	1060	18	20
Unheated control	970	18	15
250° F/8 hr	800[b]	16	20
	900	16	25
	1000	23	21
	950	14	20
	930	15	20
Unheated control	1160	13	26
250° F/10 hr	780	20	23
	920	18	24
	840	13	29
	870	13	18
	990	13	19
Unheated control	1140	15	20
250° F/12 hr	760	10	20
	740	10	13
	700	15	20
	820	15	18
	790	13	19

[b]See text, page 6.

Exposure	Peak Pressure (psi)	Time (ms)	
		Ignition Delay	Rise
Unheated control	1210	13	26
250° F/14 hr[b]	810	16	30
	1130	14	21
	1130	12	19
	1070	12	29
	1080	11	21
	870	12	29
	920	14	29
	990	11	22
	1040	14	21
	1080	12	21

[b]See text, page 6.

APPENDIX II

BALLISTIC DATA, HIGH TEMPERATURE-EXPOSED M2 PROPELLANT IN M73 CARTRIDGE/M3 INITIATOR SYSTEM

Firing temperature: 70° F (Ambient)

Exposure	Peak Pressure (psi)	Time (ms) Ignition Delay	Time (ms) Rise
Unheated control	1070	13	20
	1110	15	21
	1210	14	17
	1140	14	16
	1060	14	19
225° F/24 hr	1070	13	21
	1020	15	17
	1040	15	21
	1010	13	17
	890	14	20
	1020	16	16
	1040	14	17
	940	16	16
	980	15	20
	1100	16	19
225° F/48 hr	900	14	22
	1000	14	22
	840	18	27
	910	15	17
	950	15	23
	-[a]	-	-
	940	15	25
	1010	16	22
	940	14	15
	970	14	15
225° F/72 hr	840	13	23
	800	14	22
	740	13	25
	990	11	15
	920	13	14
	790	15	21
	-[a]	-	-
	820	15	20
	710	14	20
	930	16	21

[a]Misfired.

Exposure	Peak Pressure (psi)	Time (ms) Ignition Delay	Rise
225° F/96 hr	860	10	15
	700	11	17
	720	11	16
	690	12	19
	-[a]	-	-
	840	13	13
	520	13	16
	610	13	18
	880	10	14
225° F/120 hr	510	15	11
	-[a]	-	-
	800	15	11
	760	15	11
	680	16	11
	640	17	12
	820	16	11
	500	17	17
225° F Repeat Exposures			
Unheated control	1130	15	17
	1080	15	18
	910	14	18
	1040	14	19
	1080	14	16
225° F/24 hr	1040	17	15
	1090	13	16
	1010	13	21
	970	14	19
	1040	12	20
	1080	12	17
	970	14	20
	1060	13	17
	990	14	19
	1000	16	19

[a]Misfired.

Exposure	Peak Pressure (psi)	Time (ms) Ignition Delay	Rise
225° F/48 hr	860	13	16
	-[a]	-	-
	940	14	18
	940	12	14
	1010	12	16
	930	13	13
	900	12	14
	940	14	16
	980	13	14
	900	13	17
225° F/72 hr	810	12	19
	700	14	25
	730	14	17
	740	15	16
	740	14	17
	890	11	15
	980	12	12
	850	12	16
	840	11	15
	790	13	18
225° F/96 hr	920	11	13
	-[a]	-	-
	820	11	14
	-[a]	-	-
	640	13	21
	680	13	16
	-[a]	-	-
	620	12	22
225° F/120 hr	520	15	16
	510	14	17
	630	13	18
	520	14	18
	640	11	16
	590	12	13
	500	14	14
	580	13	14
	560	14	14
	770	11	15

[a]Misfired.

Exposure	Peak Pressure (psi)	Time (ms) Ignition Delay	Rise
225° F/144 hr	500	12	19
	690	11	15
	490	15	16
	440	14	16
	540	12	16
	430	15	20
	430	15	16
	570	13	16
	320	13	19
	520	14	17
	250° F Exposures		
Unheated control	1260	15	17
	1120	14	17
	1260	14	17
	1220	16	16
	1140	14	18
250° F/2 hr	1240	13	16
	1240	14	19
	1110	14	16
	1060	15	18
	1170	15	19
250° F/4 hr	1050	15	17
	1110	13	17
	1090	14	16
	1110	13	17
	1140	15	17
250° F/6 hr	1140	15	17
	1100	14	18
	1140	14	17
	1160	12	14
	1090	14	18
250° F/8 hr	1190	13	20
	1100	13	14
	1100	12	15
	1080	12	17
	930	22	17

APPENDIX III

BALLISTIC DATA, HIGH TEMPERATURE-EXPOSED M10 PROPELLANT IN M73 CARTRIDGE/M3 INITIATOR SYSTEM

Firing temperature: 70° F (Ambient)

Exposure	Peak Pressure (psi)	Time (ms) Ignition Delay	Rise
Unheated control	890	16	20
	970	16	18
	930	[illegible]	20
	990	15	19
	970	15	20
225° F/12 hr	980	15	18
	860	15	19
	900	28	18
	980	15	18
	920	14	19
225° F/24 hr	1040	16	18
	970	17	19
	880	17	20
	940	16	19
	1080	14	20
225° F/48 hr	900	16	20
	820	14	22
	840	27	23
	840	14	21
	930	17	21
225° F/72 hr	840	31	20
	970	17	21
	840	29	26
	960	17	24
	890	16	21
225° F/96 hr	800	17	23
	750	16	24
	840	16	24
	-[a]	-	-
	790	16	23

[a]Misfired.

Exposure	Peak Pressure (psi)	Time (ms) Ignition Delay	Rise
225° F/120 hr	- [a]	-	-
	660	16	28
	610	18	32
	640	17	27
	670	18	30
225° F/144 hr	510	14	48
	440	15	31
	400	19	43
	390	19	36
	520	19	32
225° F/168 hr	330	15	38
	430	17	43
	490	16	38
	510	17	30
	420	17	44
225° F/192 hr	440	14	50
	440	14	35
	430	15	38
	470	15	31
	440	16	32
225° F/216 hr	330	12	33
	380	13	34
	440	16	35
	300	16	42
	480	16	28

[a]Misfired.

APPENDIX IV

WEIGHT LOSS vs TIME,
NITRATE ESTER PROPELLANTS AT 2[illegible]5° F

Exposure Time (hr)	Weight Loss (%)		
	M5 Propellant	M2 Propellant	M10 Propellant
24	7.2	3.4	1.2
48	11.2	12.2	0.5
72	24.8	19.4	1.7
96	30.6	24.2	2.2
120	39.2	26.7	5.4
144	-	37.5	6.8
168	-	-	10.5
192	-	-	11.2
216	-	-	16.1

NOTE: Propellants sealed in M73 cartridge (see DISCUSSION).

APPENDIX V

NITROGEN CONTENT OF NITROCELLULOSE FROM PROPELLANTS HEATED AT 225° F

	M5 Propellant		M10 Propellant
Exposure	% Nitrogen in Nitrocellulose	% Nitrocellulose Recovered	% Nitrogen in Nitrocellulose
Unheated control	13.2[a]	82[a]	13.2[a]
225° F/16 hr	13.0	81	-
225° F/24 hr	12.9	78	12.6
225° F/48 hr	12.5	76	-
225° F/72 hr	12.1	72	12.6
225° F/96 hr	12.0	62	-
225° F/144 hr	11.5	53	12.0
225° F/216 hr	-	-	11.4

[a]Original propellant composition.

APPENDIX VI

MAJOR GAS COMPONENTS,[a] HEATED M73 CARTRIDGES CONTAINING M5 PROPELLANT

Exposure	Moles Percent O_2	CO_2	CO	NO	N_2O	N_2	Gas at STP (ml)
Dry air[b]	20.95	0.03	-	-	-	78.09	-
Unheated control							
A	20.0	0.0	-	-	-	76.7	1
B	20.5	0.2	-	-	-	74.1	1
225° F/16 hr							
A	0.0	51.2	6.9	1[illegible].1	16.2	23.9	13
B	0.0	46.4	5.9	16.1	14.1	25.5	13
225° F/24 hr							
A	0.0	30.6	7.6	4.2	7.5	47.7	5
B	0.0	34.5	6.0	2.5	9.6	45.5	10
225° F/48 hr							
A	0.0	40.7	6.3	1.6	8.2	40.1	24
B	0.0	35.5	6.9	1.2	6.0	46.3	3
225° F/72 hr							
A	0.7	58.1	2.6	0.0	6.4	19.4	5
B	0.0	40.4	7.0	0.7	7.1	38.6	41
225° F/96 hr							
A	0.0	50.4	5.8	0.8	6.5	32.5	4
B[c]	-	-	-	-	-	-	-
225° F/120 hr							
A	0.0	56.3	5.6	0.5	10.8	30.8	93
B	0.0	47.7	1.0	0.6	8.6	60.7	95
225° F/144 hr							
A	0.0	55.0	4.9	0.9	10.1	33.5	83
B	0.0	49.3	5.9	1.0	8.6	39.5	72
250° F/2 hr	0.0	27.9	7.6	12.8	8.0	46.6	6
250° F/4 hr	0.0	34.9	9.0	4.1	9.4	46.0	10
250° F/8 hr	0.0	51.3	6.7	1.2	11.5	30.3	46
250° F/16 hr	0.0	30.2	10.4	3.9	8.3	47.7	5
275° F/1 hr	0.0	14.4	4.4	6.7	3.6	70.2	3
275° F/2 hr	0.2	22.2	11.0	9.5	6.7	51.7	5

[a]Argon, H_2O, and trace quantities of impurities omitted.
[b]Typical analysis for comparison.
[c]Faulty sample due to leak.

APPENDIX VII

MAJOR GAS COMPONENTS,[a]
HEATED M73 CARTRIDGES CONTAINING M2 PROPELLANT

Exposure	Moles Percent O_2	CO_2	CO	NO	N_2O	N_2	Gas at STP (ml)
Dry air[b]	20.95	0.03	-	-	-	78.09	-
225° F/24 hr							
A	0.0	43.4	6.3	3.8	11.5	33.8	18
B	0.0	41.7	7.7	3.5	11.1	34.5	18
225° F/48 hr							
A	1.2	52.9	3.0	0.2	18.3	28.0	77
B[c]	-	-	-	-	-	-	-
225° F/72 hr							
A	0.2	63.3	1.9	0.3	14.6	19.6	82
B	0.5	59.2	2.4	0.5	14.5	21.6	>100
225° F/96 hr							
A	0.0	62.6	2.4	0.5	14.5	20.3	>100
B	0.3	60.0	2.2	0.3	14.1	22.0	>100
225°F/120 hr							
A	0.0	62.0	2.2	0.7	12.5	22.2	>100
B	0.4	58.8	3.1	0.2	12.4	25.0	>100
225° F/144 hr							
A	0.0	30.1	10.8	0.5	3.6	55.8	43
B[c]	-	-	-	-	-	-	-
250° F/2 hr							
A	0.0	24.0	9.2	13.0	4.1	48.0	4
B	0.1	21.1	8.1	12.0	3.3	45.6	3
250° F/4 hr							
A	0.0	36.0	9.0	7.5	5.8	42.3	8
B	0.0	32.8	9.7	7.5	4.7	45.5	8
250° F/6 hr							
A	0.9	8.2	13.6	0.0	0.4	76.4	5
B[c]	-	-	-	-	-	-	-

[a]Argon, H_2O, and trace quantities of impurities omitted.
[b]Typical analysis for comparison.
[c]Faulty sample due to leak.

APPENDIX VIII

MAJOR GAS COMPONENTS,[a]
HEATED M73 CARTRIDGES CONTAINING M10 PROPELLANT

Exposure	Moles Percent						Gas at STP (ml)
	O_2	CO_2	CO	NO	N_2O	N_2	
Dry air[b]	20.95	0.03	-	-	-	78.09	-
225° F/16 hr							
A	5.4	4.6	4.9	0.0	0.4	83.8	2
B	6.1	3.3	6.2	0.0	0.5	83.8	1
225° F/24 hr							
A	0.1	7.0	7.9	0.3	1.7	82.2	1
B	0.2	6.7	7.3	0.1	1.8	82.6	1
225° F/48 hr							
A	1.5	7.9	10.5	[illegible]	0.5	78.5	-
B	0.0	8.7	16.7	1.8	0.9	72.1	3
225° F/72 hr							
A	0.2	9.0	13.9	0.1	1.1	[illegible]	3
B[c]	-	-	-	-	-	-	-
225° F/96 hr							
A	0.0	12.2	[illegible]	0.3	0.9	74.1	8
B	1.1	7.0	12.8	0.2	0.7	78.3	6
225° F/120 hr							
A	0.0	16.3	16.4	0.4	1.0	65.9	15
B	0.3	9.0	14.5	0.0	0.8	73.5	11
225° F/144 hr							
A	0.5	11.3	15.3	0.1	0.8	71.4	10
B	0.5	12.1	14.6	0.2	0.7	71.6	12
225° F/168 hr							
A	0.3	16.5	13.8	0.3	0.6	67.3	9
B	0.2	10.6	15.9	0.1	0.7	71.1	12
225° F/192 hr							
A	0.0	18.7	15.3	0.7	1.5	63.1	21
B	0.0	19.0	15.2	0.7	1.3	63.3	21
225° F/216 hr							
A	0.0	20.6	15.2	0.7	1.8	61.9	21
B	0.1	14.1	17.2	0.4	0.9	66.3	12
250° F/4 hr							
A	[illegible]	7.3	7.6	0.0	1.4	81.4	2
B	3.3	6.2	[illegible]	0.0	1.2	81.0	[illegible]
250° F/8 hr							
A	0.0	11.2	9.3	4.5	2.1	71.2	4
B	0.1	8.5	10.1	1.0	1.7	77.7	3
275° F/2 hr							
A	0.0	11.2	12.0	3.1	1.9	71.1	6
B	0.0	14.1	10.1	4.3	1.9	67.7	6

[a] Argon, H_2O, and trace quantities of impurities omitted.
[b] Typical analysis for comparison.
[c] Faulty sample due to leak.

APPENDIX IX

BALLISTIC DATA, DISC COMPOSITE PROPELLANT IN M73 CARTRIDGE/M3 INITIATOR SYSTEM

Propellant	Charge Weight (gm)	Avg Web (in.)	O.D. (in.)	Peak Pressure (psi)	Time (ms) Ignition Delay	Rise
M5 (standard)	2.8	0.039	-	1010	15	21
	2.8	0.039	-	1[illegible]10	15	20
A[illegible]T 623	2.5	0.040	0.10	1030	10	16
	2.5	0.040	0.10	1050	13	15
ANR 2753BI	2.5	0.040	0.20	1040	13	15
	2.5	0.040	0.20	1020	10	16
Arcite 406	2.5	0.040	0.10	640	18	14
	2.5	0.040	0.10	870	15	16
	2.5	0.040	0.20	890	15	20
	2.5	0.040	0.20	890	16	18
GCR 400	2.5	0.040	0.10	1040	16	15
	2.5	0.040	0.10	1140	14	18
	2.5	0.040	0.20	1210	14	13
	2.5	0.040	0.20	1170	15	14
GCR 310	2.5	0.040	0.10	690	21	23
	2.5	0.040	0.10	690	19	20
GCR 700	2.5	0.040	0.10	860	11	18
	2.5	0.040	0.10	920	10	18
	2.5	0.040	0.20	860	15	16
	2.5	0.040	0.20	840	18	15
GCR 701	2.5	0.040	0.10	880	16	15
	2.5	0.040	0.10	900	15	14
	2.5	0.040	0.20	890	15	20
	2.5	0.040	0.20	890	15	20

APPENDIX X

BALLISTIC DATA, GRAPHITE-COATED DISC COMPOSITE PROPELLANT IN M73 CARTRIDGE/M3 INITIATOR SYSTEM

Propellant	Charge Weight (gm)	Avg Web (in.)	O.D. (in.)	Peak Pressure (psi)	Time (ms) Ignition Delay	Rise
M5 (standard)	2.8	0.039	-	1080	15	23
	2.8	0.039	-	1350	18	23
	2.8	0.039	-	1240	21	18
	2.8	0.039	-	1340	18	20
	2.8	0.039	-	980	20	18
	2.8	0.039	-	1160	18	23
GCR 400	2.5	0.040	0.10	1260	15	18
	2.5	0.040	0.10	1160	15	19
	2.5	0.040	0.10	1060	25	18
	2.7	0.040	0.10	1220	18	18
	2.7	0.040	0.10	1420	15	18
	2.7	0.040	0.10	1500	18	20
	2.5	0.040	0.20	1260	18	18
	2.5	0.040	0.20	1280	15	18
	2.5	0.040	0.20	1290	14	19
	2.7	0.040	0.20	1450	15	18
	2.7	0.040	0.20	1400	15	20
	2.7	0.040	0.20	1380	16	19
GCR 700	2.5	0.040	0.10	1030	18	20
	2.5	0.040	0.10	1100	15	23
	2.5	0.040	0.10	1110	18	20
	2.7	0.040	0.10	1400	15	18
	2.7	0.040	0.10	1420	12	21
	2.7	0.040	0.10	1340	16	18
	2.5	0.040	0.20	1290	11	24
	2.5	0.040	0.20	1230	15	20
	2.5	0.040	0.20	1280	13	20
	2.7	0.040	0.20	1410	15	18
	2.7	0.040	0.20	1330	15	18
	2.7	0.040	0.20	1320	15	20
GCR 701	2.5	0.040	0.10	880	14	16
	2.5	0.040	0.10	770	15	18
	2.5	0.040	0.10	970	14	16
	2.7	0.040	0.10	1050	15	19
	2.7	0.040	0.10	1040	15	20
	2.7	0.040	0.10	1110	18	15
	2.5	0.040	0.20	970	20	20
	2.5	0.040	0.20	900	23	20
	2.5	0.040	0.20	880	20	23
	2.7	0.040	0.20	- [a]	-	-
	2.7	0.040	0.20	960	18	23
	2.7	0.040	0.20	990	20	20

[a]Range malfunction.

APPENDIX XI

BALLISTIC DATA, COMPOSITE PROPELLANTS
IN M73 CARTRIDGE/M3 INITIATOR SYSTEM

Firing temperature: -65° F (low)

Propellant	Charge weight (gm)	Avg Web (in.)	O.D. (in.)	Peak Pressure (psi)	Time (ms) Ignition Delay	Time (ms) Rise
ANR 2753BI	2.5	0.040	0.20	1360	13	16
	2.5	0.040	0.20	1120	11	18
	2.5	0.040	0.20	1190	11	19
	2.5	0.040	0.20	1090	14	19
	2.5	0.040	0.20	1100	13	19
GCR 400	2.5	0.040	0.10	1190	16	20
	2.5	0.040	0.10	1210	16	15
	2.5	0.040	0.10	1170	15	18
	2.5	0.040	0.10	1110	16	16
	2.5	0.040	0.10	1110	16	18
	2.5	0.040	0.20	1300	13	16
	2.5	0.040	0.20	1120	14	18
	2.5	0.040	0.20	1150	14	15
	2.5	0.040	0.20	1070	16	18
	2.5	0.040	0.20	1130	15	15
GCR 700	2.5	0.040	0.10	1040	15	15
	2.5	0.040	0.10	1100	14	18
	2.5	0.040	0.10	1220	14	19
	2.5	0.040	0.10	1040	14	19
	2.5	0.040	0.10	1050	15	18
GCR 701	2.7	0.040	0.10	1240	13	16
	2.7	0.040	0.10	1170	13	19
	2.7	0.040	0.10	1130	13	19
	2.7	0.040	0.10	1150	15	19
	2.7	0.040	0.10	1140	14	19
	2.7	0.040	0.20	1130	15	23
	2.7	0.040	0.20	1120	15	24
	2.7	0.040	0.20	1050	15	25
	2.7	0.040	0.20	1010	18	23
	2.7	0.040	0.20	960	18	21

APPENDIX XII

BALLISTIC DATA, HIGH TEMPERATURE-EXPOSED COMPOSITE PROPELLANT
IN M CARTRIDGE/M3 INITIATOR SYSTEM

Firing temperature: 70° F (ambient)

Propellant	Web (in.)	O.D (in.)	Exposure	Peak Pressure (psi)	Time (ms) Ignition Delay	Rise
M5 (standard)	-	-	Unheated	1440	18	20
	-	-	"	1130	15	14
	-	-	"	1320	19	23
	-	-	"	1330	15	20
	-	-	"	1310	18	20
GCR 400	0.040	0.10	400° F/2 hr	1160	16	19
	0.040	0.10	400° F/2 hr	1130	15	20
	0.040	0.10	400° F/2 hr	1030	19	18
	0.040	0.10	400° F/2 hr	1030	16	23
	0.040	0.10	400° F/2 hr	1010	15	20
	0.040	0.20	400° F/2 hr	1200	15	19
	0.040	0.20	400° F/2 hr	1140	15	20
	0.040	0.20	400° F/2 hr	1110	15	20
	0.040	0.20	400° F/2 hr	1090	15	20
	0.040	0.20	400° F/2 hr	1100	19	16
GCR 700	0.040	0.10	400° F/2 hr	880	16	19
	0.040	0.10	400° F/2 hr	- [a]	-	-
	0.040	0.10	400° F/2 hr	1110	13	18
	0.040	0.10	400° F/2 hr	1050	15	18
	0.040	0.10	400° F/2 hr	1070	18	15
	0.040	0.20	400° F/2 hr	1040	13	18
	0.040	0.20	400° F/2 hr	1070	15	18
	0.040	0.20	400° F/2 hr	1050	14	18
	0.040	0.20	400° F/2 hr	1160	13	19
	0.040	0.20	400° F/2 hr	1110	14	16
GCR 701	0.040	0.10	400° F/2 hr	1210	13	15
	0.040	0.10	400° F/2 hr	1290	13	19
	0.040	0.10	400° F/2 hr	1150	10	19
	0.040	0.10	400° F/2 hr	1150	16	19
	0.040	0.10	400° F/2 hr	1240	13	19
	0.040	0.20	400° F/2 hr	1130	18	21
	0.040	0.20	400° F/2 hr	1110	16	25
	0.040	0.20	400° F/2 hr	1190	19	21
	0.040	0.20	400° F/2 hr	1090	19	19
	0.040	0.20	400° F/2 hr	1120	19	21
GCR 400	0.040	0.10	400° F/4 hr	1040	16	19
	0.040	0.10	400° F/4 hr	1010	18	20
	0.040	0.10	400° F/4 hr	960	20	20
	0.040	0.10	400° F/4 hr	1010	19	20
	0.040	0.10	400° F/4 hr	1010	18	18
	0.040	0.20	400° F/4 hr	1050	19	18
	0.040	0.20	400° F/4 hr	1000	14	19
	0.040	0.20	400° F/4 hr	1040	19	20
	0.040	0.20	400° F/4 hr	1140	18	15
	0.040	0.20	400° F/4 hr	1130	18	13
GCR 300	0.040	0.10	400° F/4 hr	960	18	18
	0.040	0.10	400° F/4 hr	1010	18	18
	0.040	0.10	400° F/4 hr	990	18	15
	0.040	0.10	400° F/4 hr	920	16	20
	0.040	0.10	400° F/4 hr	920	15	15
	0.040	0.20	400° F/4 hr	950	15	18
	0.040	0.20	400° F/4 hr	960	15	18
	0.040	0.20	400° F/4 hr	980	15	21
	0.040	0.20	400° F/4 hr	880	18	15
	0.040	0.20	400° F/4 hr	1000	15	18
GCR 701	0.040	0.10	400° F/4 hr	1060	6	20
	0.040	0.10	400° F/4 hr	[illegible]	[illegible]	20
	0.040	0.10	400° F/4 hr	[illegible]	19	18
	0.040	0.10	400° F/4 hr	960	18	19
	0.040	0.10	400° F/4 hr	1080	19	16
	0.040	0.20	400° F/4 hr	890	19	25
	0.040	0.20	400° F/4 hr	950	16	25
	0.040	0.20	400° F/4 hr	960	18	24
	0.040	0.20	400° F/4 hr	[illegible]	21	23
	0.040	0.20	400° F/4 hr	880	15	17
M5 (standard)	-	-	Unheated	1120	15	20
	-	-	"	1150	18	18
	-	-	"	1160	18	20
	-	-	"	1250	18	23
	-	-	"	1250	13	17

[a] Range malfunction.

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Single and double base propellants, as used in propellant actuated device (PAD) cartridges, were subjected to high temperature conditions short of autoignition. Their thermal deterioration was measured by decy in peak pressures in firings in the M73 PAD Cartridge/M3 Initiator system and by estimation of weight loss, change in nitrogen content of nitrocellulose, gas evolution, and grain deformation. The propellants degraded rapidly at 225° and 250° F, and would not survive ~~270~~ 275° F exposure to permit evaluation.

The ballistic feasibility of substituting composite propellatns for nitrate esters in PAD cartridges was demonstrated in the M73 cartridge. This required hand-tailoring of grains because composite propellants in gun-type geometries were not available from major composite propellant sources.

Composite propellants employing ammonium perchlorate oxidizer performed satisfactorily in the M73 Cartridge/M3 Initiator system at -65° F, but were marginal after two hours' exposure at 400° F.

It is recommended that efforts be continued for the development of composite propellants employing potassium perchlorate oxidizer to withstand -65° to +400° F soak temperatures.

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